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CANADIAN COMBUSTION RESEARCH LABORATORY

OCTOBER 1978

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
REPORT ERP/ERL 78-78 (TR)

PILOT-SCALE COMBUSTION EVALUATION OF MANALTA BRIQUETTES

by

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ABSTRACT

The combustion performance of Manalta briquettes, produced by fluid-bed drying and subsequent briquetting of a run-of-mine Onakawana lignite, was evaluated in a pilot-scale pulverized-fired research boiler.

The briquettes, which contained 10% total moisture, handled and pulverized easily, ignited readily and produced a stable flame. The ash showed evidence of slagging on high temperature boiler surfaces, although both high and low temperature corrosion were minimal.

The flames were not intense and nitric oxide generation was therefore low. Sulphur oxide emissions were close to 100% of their theoretical value. The fly ash contained below 2% carbon, which constituted a thermal penalty of less than 1%; this carbon content did not affect the fly ash resistivity which was measured in situ to be 7.5×10^9 at 150°C. It is anticipated that this fuel would not create any precipitation problems in cold precipitators.

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1. INTRODUCTION

During 1977 the Manalta Coal Company was awarded a research contract under the Canada Centre Mineral and Technology (CANMET) Coal Conversion Program to determine the technological feasibility of a scheme to dry lignite and use the dry product in utility boilers.

Onakawana lignite from northern Ontario was dried in a roller mill drier, crushed to 77% below 65-mesh, collected in a bag house and briquetted using a binderless pressure technique. The end product, which contained 10% moisture, could be shipped without degradation to the point of use. In this way the charges associated with transporting a 45% moisture lignite were minimized.

As part of the program the Canadian Combustion Research Laboratory (CCRL) carried out a combustion evaluation of the final product. The project was carried out as a low grade fuel evaluation within the Energy Research Research Program of CANMET.

2. RESEARCH OBJECTIVES

The objectives of the combustion trials and related analytical studies were:

a) to observe the comminution and handling characteristics of the briquettes

b) to evaluate the combustion performance of the pulverized briquettes at three excess-air levels

c) to characterize the particulate and gaseous pollutants generated during combustion

d) to assess the slagging and fouling potential of the ash constituents in the fuel on radiant and convective heat transfer surfaces

e) to assess the corrosion potential of condensed sulphuric acid on cold-end boiler surfaces

f) to determine the fly-ash resistivity characteristics and assess the ease of fly-ash collection by electrostatic precipitation.

3. COAL CHARACTERISTICS

A one-ton sample of the lignite briquettes was delivered to CCRL in sealed drums. The briquettes, with "as received" moisture of 11% were totally free from visible moisture and had travelled without excessive degradation. The analysis of the briquettes is given in Table 1.

No problems were experienced in moving or feeding this fuel through the CCRL pilot-scale coal handling system.

The briquettes, which rank as lignitic, appear from analysis to be acceptable for use in most coal handling equipment.

The cellulosic nature of lignites normally produces a reactive pulverized fuel whose flame stability is modified only by the moisture and ash content of the burner feed. The total inert content (moisture plus ash) of the briquette is 27%; this will undoubtedly lead to stable flames and higher flame temperatures than are common with direct firing of raw lignites, which usually contain 30 - 40% moisture.

One comparative index that can be calculated from the proximate and ultimate analyses is the volatile matter combustion temperature or the adiabatic gas temperature achieved by a stoichiometric mixture of the volatile material in coal and air. In this calculation, the coal is assumed to be dry, the combustion air is assumed to carry all the moisture in the coal as fed to the pulverizer, and volatile matter combustion is considered to be complete prior to fixed-carbon combustion.

Volatile-matter combustion temperatures for the Manalta briquettes are shown in Table 2. The calculated temperature for the sample used in this project is 1016°C; this high value suggests that the coal will ignite easily, that combustion will be stable, and that pulverized Manalta briquettes will be more reactive than either Sundance coal or Utility lignite, both of which are now being burned successfully in large thermal power boilers.

4. PILOT-SCALE RESEARCH BOILER

The CCRL pilot-scale research boiler, illustrated schematically in Figure 1, is a pulverized-coal-fired boiler incorporating two opposed in-shot burners that tilt downward over a refractory chamber. The furnace is of membrane-wall construction and operates at pressures up to 25 cm water column.

At the full-load firing rate of 2500 MJ/h the boiler generates 730 kg/h steam. The heat is dissipated in an air cooled condenser. During the tests with Manalta briquettes the firing rate was held at approximately 75 kg/h (1400 MJ/h).

Crushed fuel is supplied from a 4500-kg hopper mounted on an electronic weigh scale through a variable-speed worm feeder to a ring and roller type of pulverizer, which is normally swept and pressurized by air at any temperature up to 230°C or, if necessary, with a mixture of air and flue gas at up to 490°C. The pulverizer contains a motor-driven classifier for controlling coal fineness, and a riffle at the pulverizer outlet proportions the coal to the two burners. Secondary air can be supplied to the burner at any temperature up to 260°C.

Combustion gases leave the furnace between 760°C and 860°C and then pass through a transition section, a test-air heater and a conventional three pass air heater before entering a long horizontal sampling duct. At the end of the sampling duct, the gas flow can either be passed entirely into the stack or, if necessary, a portion of the gas flow to the stack can be diverted isokinetically into a small two-stage electrostatic precipitator. A by-pass from the air heater to the stack breeching and additional heat exchanger surface in the sampling duct permit the gas temperature in the sampling duct to be varied between 150°C and 300°C.

A forced-draft fan supplies air to the air heater at 0.07 atm. The air, on leaving the heater, is divided into three streams: primary air to the pulverizer, secondary air to the burners and cooling air to the test-air heater. The last stream, after leaving the test-air heater, can be either exhausted to the atmosphere or blended with the primary-air supply to the pulverizer.

The research boiler is manually controlled, except for electrical interlocks to ensure that safe start-up and shutdown procedures are followed. When burning high-grade coals, it has been possible to operate with as little as 1.0% O_2 and no more than 0.1% CO in the flue gases, with a smoke density of less than No. 1 Ringelmann. When severe fouling of the convective heat-transfer surfaces occurs, firing-rate or excess-air level must be reduced to control furnace pressure.

5. EXPERIMENTAL PROCEDURES

5.1 Operating Procedures

The operating procedure given below was used for all tests with some minor variations in timing as necessary.

1. Before each test, all boiler and air heater fireside surfaces were cleaned by air lancing. Ash deposits sintered to refractory surfaces were manually removed. Sufficient coal was bunkered to provide approximately 10 h of operation at the desired feed rate.
2. At 0600 h, the cold boiler was fired up on No. 2 fuel oil at 16 gph. Excess-air was adjusted to provide 3% O_2 in the flue-gas and the boiler was allowed to stabilize at full steaming rate and pressure. All continuous monitoring instruments were put into service.
3. At 0730 h, feed of pulverized coal to the boiler was started with the specified classifier speed, mill temperature and excess-oxygen in the flue gas. One oil torch was left in operation.
4. At 0745 h, the oil torch was removed, leaving the boiler operating on pulverized coal only.
5. At 0900 h, scheduled testing was begun. Boiler panel readings were recorded hourly. The specified coal feed rate and excess-oxygen level were maintained as closely as possible.
6. By 1500 h, scheduled tests were nearing completion. Repeat measurements were begun if required.
7. When all measurements were completed, an oil torch was inserted and coal feed to the pulverizer was shut off. When the pulverizer was empty, the boiler was shut down.
8. The furnace was allowed to cool overnight. Then the furnace bottom was removed and the ash remaining in the furnace bottom and boiler hoppers was collected and weighed.

5.2 Parameters of Combustion Performance

The following parameters of combustion performance were measured in each test at appropriate measuring stations (as indicated in Figure 1).

Proximate, ultimate and ash analyses and ash fusion determinations of samples taken from a bulk sample of crushed coal obtained by hourly grab samples at the pulverizer inlet. Station 1.

Moisture and sieve analyses of samples of pulverized coal taken every two hours at the pulverizer outlet. Station 2.

CO_2 and CO content of the flue-gas, measured continuously by infra-red monitors. Station 3.

O_2 content of the flue gas, measured continuously by a paramagnetic monitor. Station 3.

NO content of the flue gas, measured continuously by a chemiluminescent monitor. Station 4.

SO_2 content of the flue gas, measured continously by a chemilfluorescent monitor. Station 5.

SO_2 and SO_3 content of the flue gas, measured by the API and the Shell-Thornton methods, respectively, two or three times per test. Station 6.

Low-temperature corrosion potential, measured by three mild-steel probes inserted simultaneously into the flue gas stream and maintained at three different temperatures for the duration of the combustion test. Station 4.

Fly-ash loading, measured isokinetically by an automated sampling system, two to four samples per test. These samples were analyzed for carbon content, chemical composition and size distribution. Station 7.

Ash fouling of heat-transfer surfaces evaluated by examination of deposits on a simulated superheater, installed immediately downstream of the screen tubes to accommodate studies of fly-ash build-up on high-temperature boiler tube surfaces. A second method of evaluating ash fouling was by examination of the thickness, physical structure, chemical composition and melting characteristics of ash deposits selected from various parts of the furnace and air heater after shutdown.

Electrostatic precipitator efficiency, measured by passing part of the flue gas through a small electrostatic precipitator for a period of 45 minutes, three samples per test. The efficiency was calculated from the measured inlet and outlet dust loadings. Station 8.

Fly-ash resistivity, measured by an in-situ, point-plane resistivity apparatus at flue gas temperatures of 200°C and 400°C, two measurements at each location per test. Stations 4 and 7. A series of static isothermal measurements on selected samples of fly ash extracted from the gas stream at the precipitator inlet were also made.

In addition, qualitative observations on flame appearance and length were logged. When the furnace was sufficiently cooled after a test, the superheater and furnace walls were photographed.

Three combustion tests were planned at excess oxygen levels of 5, 3 and 1 per cent respectively. Ash deposition studies were carried out at the two highest excess oxygen levels but the limited quantity of briquettes available restricted the duration of the trial at the lowest level. Data from this trial was restricted to burn-out and fly-ash characteristics.

6. COMBUSTION PERFORMANCE

6.1 Coal Comminution

The "as received" coal was crushed, metered and pulverized to the selected degree of fineness without difficulty. It was then transported directly to the burner without moisture separation from the carrying air; no blockage or segregation occurred in either of the coal pipes to the boiler. The size distribution of the pulverized coal used in each combustion test is shown in Table 3.

6.2 Flame Characteristics

The combustion performance data remained essentially constant throughout each combustion trial and confirmed that the handling characteristics of the coal were excellent. The flame was bright, clean and extremely stable under all experimental conditions and an oil support flame was only required for about five minutes after the start of each trial. The flame temperature indicated by an optical pyrometer focused on one of the two opposed flames was in the range 1030°C - 1050°C; this is comparable to temperatures of 1050°C - 1100°C recorded during similar experiments with Sundance lignite. The relative steaming rates from the two fuels were also closely similar at the same excess air level.

Manalta Briquettes:	5.86 kg steam/kg Fuel
Sundance Lignite:	5.72 kg steam/kg Fuel

These numbers indicate that the performance of the Manalta briquettes within the combustion chamber of the pilot-scale research was marginally superior to that of the Sundance lignite.

6.3 Flue Gas Analyses

The flue gas analyses for the three combustion tests are shown in Table 4. The carbon monoxide concentration does not constitute either an emission problem or a significant thermal penalty.

One noticeable feature of the combustion gas analyses throughout the combustion experiments is the small magnitude of the deviations from the mean values. This can only be ascribed to the uniformity of the fuel and of its handling, which allowed the thermal input to the boiler to be controlled at a near constant level.

Sulphur dioxide concentrations measured in the combustion products are shown in Table 4. The sulphur accountability is close to 100%. This agrees with predictions from Gronhovd's equation (1), which suggest that neutralization by cations in the ash should not amount to more than 7%.

The nitric oxide concentrations at all excess-air levels were higher than those normally encountered when burning lignites in the pilot-scale boiler. This reflects the low moisture content of the briquettes which allows high flame temperatures and a consequently high yield of NO from atmospheric nitrogen. The experimental data shows that a significant reduction in nitric oxide emissions can be achieved by reducing the excess oxygen level from 5% to 3%; further reduction to 1% did not produce a further reduction in nitric oxide emission.

6.4 Fly-ash Characteristics and Coal Burn-out

The fly-ash (particulate) concentrations in the flue gas stream at the entry to the electrostatic precipitator are shown in Table 5. The fly ash retained in the boiler, consisting of both ash and unburnt carbon, is also shown.

The combustible content of the fly-ash and therefore the thermal penalty due to incomplete combustion varied with excess-oxygen level. Figure 2 shows that an insignificant maximum occurred at 3% O_2. The absolute level of this carbon content would be in all instances, totally acceptable in conventional pulverized coal firing practice. In large furnaces the burn-out of pulverized coal is generally superior to that recorded in pilot-scale equipment where flame quenching is accelerated by the high surface-to-volume ratio and short residence time.

6.5 Fly-ash Resistivity and Electrostatic Precipitator Performance

A high fly-ash electrical resistivity ($> 10^{10}$ ohm-cm) indicates that the dust can retain a strong electrical charge and/or generate a back corona within a deposit when subjected to an electrical field. Under these circumstances precipitator efficiency is reduced by electrical neutralization of charged particles migrating in the field. Conversely a fly ash with a low electrical resistivity ($>10^{7}$ ohm-cm) will precipitate readily and discharge at the collection electrode. Adhesive forces will therefore be reduced, leading to decreased precipitator efficiency caused by particle re-entrainment. Intermediate resistivity values of 10^{8} - 10^{9} ohm-cm are generally considered to yield the best precipitator performance.

The "in-situ" measurements of fly-ash resistivity made during the combustion trials together with a series of ambient air measurements are shown in Figure 3. The "in-situ" measurements show a decrease from 7.5×10^9 to 7.5×10^8 as the flue-gas temperature increased from 175°C to 250°C.

These resistivity values are close to the optimum for satisfactory precipitator performance.

The difference between the "in-situ" measurements and the ambient air measurements reflects the effect of moisture in the combustion products on the electrical behaviour of the fly ash.

Fly-ash resistivity is also known to be affected by the carbon content of the fly ash. This effect does not usually become apparent until the carbon content of the fly ash is above 5% and it not considered to have had any role in the measurements reported here.

The fly ash and resistivity analyses show that the briquettes provide a pulverized fuel which can give a totally satisfactory degree of burn out. The electrical properties of the resultant fly-ash are unlikely to create problems in electrostatic precipitation.

7. HIGH TEMPERATURE ASH DEPOSITION

Two general types of high temperature ash deposition can occur on gas-side furnaces of coal-fired boilers:

Slagging - fused deposits that form on surfaces exposed predominantly to radiant heat transfer.

Fouling - high temperature bonded deposits that form on surfaces exposed predominantly to convective heat transfer. Particularly troublesome areas are superheaters and reheaters.

An assessment of the slagging and fouling potential of the Manalta briquettes used in these pilot-scale experiments was done using accepted empirical indices based on the analysis of the raw coal, the analysis of the fireside deposits and a visual assessment of the deposits produced within the boiler. The analytical data for all the deposits accumulated throughout the boiler is presented in Tables 6 and 7.

7.1 Ash Fusion Temperatures

The deposits produced in the furnace bottom and on the refractory quarls surrounding the burner were moderately bulky and friable. They crumbled readily under moderate pressure and showed minimal evidence of surface fusion.

Deposit ash analysis and fusion characteristics are shown in Tables 6 and 7. Ash fusion determined according to procedures described in ASTM D. 1857, defines four temperatures at which physical changes in a standard specimen become apparent. The test can be carried out in either a reducing or oxidizing atmosphere; normal reference is to the reducing condition which generates lower fusion temperatures and is therefore more restrictive.

The initial deformation temperature corresponds to the temperature in an operating furnace at which the particles of coal ash, in transit through the furnace, have been cooled to a point where they still retain a sligh tendency to stick together or to build up slowly on heat-absorption surfaces. When the temperatures in an operating furnace are such that the ash particles have cooled to a temperature lower than their initial-deformation temperature, they tend to accumulate as a "dry" product.

The softening temperature of the ash and the hemispherical temperature are related to a point at which the fuel ash shows a greatly accelerated tendency to mass together and stick in large quantities to heat absorbing surfaces.

The fluid temperature of the ash is a temperature above which the ash can be expected to flow in streams, drip from heat absorption surfaces, or produce a heavy clinker on the grates under a fuel bed.

The fusion characteristics of the deposits produced in these experiments (Tables 6 and 7) show that initial deformation occurs at 1160°C - 1220°C and that the melting range to fluidity is 110°C to 170°C irrespective of the atmospheric condition. This range is small and it can be anticipated that, if deposits occur on uncooled components within the boiler system they will quickly convert to a molten phase.

The fusion temperatures of the furnace bottom and wall deposits are lower than those recorded for the parent ash. The difference is marginal and indicates only minor preferential volatilization of the fluxing components Na_2O and K_2O during the combustion process.

The fusion temperatures are in the range representative of many Canadian lignites and do not constitute a problem in a boiler designed to accommodate this ash characteristic. If the fuel is used as a replacement fuel, however, it is to be anticipated that increased slagging and fouling will occur. Clearly, modification of the sootblowing schedules will minimize the problem.

7.2 Slagging Indicators

The assessment of slagging potential in pulverized or crushed coal-fired boilers has been attempted by several workers who have produced indices or composite parameters to describe the nature and severity of the slag deposits (2). These indices are frequently described as "specific" in the sense that they reflect the type of combustion equipment used in a particular unit.

Many ash slagging indices are described as being applicable only to coals with "eastern type" ash or to coals with "western type" ash. The term "western type" ash is defined as an ash having more $CaO + MgO$ than Fe_2O_3 when all are measured as weight per cent of the coal ash. It must be remembered that the criterion is dependent on ash analysis and does not have any rank or geographic connotation.

Ash low in iron and high in calcium behaves differently in a boiler than the normal high iron, low calcium eastern coals. Most parameters used for judging the slagging and fouling characteristics of eastern coals do not apply when the coal has a western type ash. Generally there is little question as to whether the ash is of a western or eastern type. In a few cases, particularly with Texas lignite, iron and dolomite constituents may both be relatively high and some question arises as to which parameters to use.

The results presented in Table 1 show clearly that the Manalta briquettes have a typical $\{CaO + MgO\}:\{Fe_2O_3\}$ ratio between 1.75 and 2.0. The coal therefore classifies as a "western" coal. The importance of this will become apparent in the following discussion of three common indices for determining slagging potential.

7.2.1 The Base:Acid Ratio

The Base:Acid Ratio is defined as

$$\frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + TiO_2}$$

where each oxide is expressed as % of total ash.

A maximum value of 0.5 for the base to acid ratio has sometimes been specified for dry bottom-pulverized-fired units although this is not a necessary restriction.

Values below 0.27 indicate that the coal is not generally suitable for use in wet-bottom units since slag viscosity will not be low enough. The value of 0.5/0.55 recorded for this coal suggest that it is not an ideal fuel for dry bottom firing but would probably be best used in a stagging system. Dry bottom firing is not precluded where the fuel is substituting for one of similar character.

7.2.2 Ash Viscosity and Slagging

To further evaluate the potential of the bottom ash to slag, the analytical data have been used to calculate the viscosity/temperature relationship for both the coal and the bottom ash deposits using the method outlined below:

$$T\ (°C) = \frac{10\ M}{\log V - C} + 150,$$

where T = Ash Temperature ^{o}C

V = Ash Viscosity, poise

$$M = 0.00835(SiO_2) + 0.00601(Al_2O_3) - 0.109$$

and

$$C = 0.0415\ (SiO_2) + 0.0192\ (Al_2O_3) + 0.0276(Fe_2O_3) + 0.016(CaO) - 3.92$$

where $SiO_2 + Al_2O_3 + Fe_2O_3 + MgO + CaO = 100$

T_{250} = Temperature (°C) at which the viscosity of a potential bottom ash slag is 250 poise with 20% of the iron in ferrous form.

For wet-bottom furnaces the preferred slag viscosity for easy tapping is below 100 poise and T_{250} should not normally exceed 1425°C.

For dry-bottom furnaces, the T_{250} can be one factor used to rate the coal ash in relation to furnace slagging.

One suggested rating system is shown below:

Slagging Category	T_{250}, °C
Low	>1275
Medium	1400 - 1150
High	1250 - 1120
Severe	<1205

It should be noted that there is considerable overlap between the categories.

The viscosity-temperature relationship calculated using the above relationship is shown in Figure 4. It is clear that the combustion process has significantly modified the viscosity characteristics of the ash.

The temperature of critical ciscosity and the temperature at which the viscosity is 250 poise are close to 1300°C. For wet-bottom furnaces the preferred viscosity is between 10 and 100 poise. The calculations presented in Figure 4 show that these viscosities occur at temperatures of 1600°C and 1300°C respectively;it appears therefore that the briquettes could be suitable for use in a wet-bottom application where the existing fuel showed a T_{250} below 1425°C.

The ash from the Manalta briquettes falls into a medium to high slagging category on the basis of the T_{250} classification.

7.3 Fouling Indicators

A most convincing indicator of the fouling tendency of the coal was the visible inspection of the deposits on the simulated superheater which was controlled at a surface temperature of 575°C. The deposits were light and friable. The coal appeared to have a low fouling tendency and the calculations of fouling indicators below was performed to determine the validity of this assessment.

7.3.1 Sodium Content of the Coal Ash

There has been general agreement between research and operating practice that the dominant factor correlating with superheater fouling is the sodium content of the coal ash.

The following classification has been proposed:

Fouling Category	% Na_2O in Ash	
	"Eastern" Coals	"Western" Coals
Low	<0.5	<2.0
Medium	0.5 - 1	2.0 - 6.0
High	1.0 - 2.5	6.0 - 8.0
Severe	>2.5	>8.0

The analysis of the coal ash and the furnace bottom deposits suggest that the coal falls into a "low" fouling category on the basis of this classification. However, it should be noted that the iron content of the coal ash and the deposits is unusually high for a "lignite" (>10%) and behaviour akin to an "eastern" coal can be anticipated. The coal should therefore be regarded as having a "medium" fouling tendency.

7.4 High Temperature Corrosion

It has been observed that alkali iron trisulphates have their minimum melting points when the molar ratio (Na:K) in the superheater deposit is 1:1.

Using the superheater deposit analysis presented in Tables 6 and 7 the molar ratio is seen to be close to 1.8 at both experimental excess-oxygen levels. This ratio is well removed from that at which the maximum corrosion occurs; no high temperature corrosion problems can be anticipated.

8. LOW TEMPERATURE CORROSION

Low temperature corrosion problems are due to the condensation of gas-phase sulphur trioxide on metal surfaces at temperatures below the acid dewpoint. The condensed acid (H_2SO_4) can then react with air heater and/or econmizer tubes to produce $FeSO_4$ as a corrosion product.

Table 8 shows the analysis of the deposits collected on cylindrical corrosion probes controlled at temperatures of 104°C, 120°C and 138°C during exposure to flue gases at 270°C. The data show that free acid accumulation was negligible at temperatures above 104°C. The probe exposed at 104°C showed a maximum acid accumulation rate of 2 $g/cm^2/h$ which is regarded as being exceptionally low. It can be expected in the majority of systems that no metal temperatures below 140°C will be encountered; the potential for low temperature corrosion is therefore extremely small.

9. CONCLUSIONS

The Manalta briquettes used in these experiments were judged to be an adequate fuel for thermal power generation. The briquettes handled and flowed readily at 10% total moisture and provided a stable fuel feed to the experimental boiler.

The flame generated by the pulverized briquettes were stable and no oil support was required at excess oxygen levels of 5, 3 and 1 per cent.

The sulphur content of the fuel is low. The extent of neutralization by the alkali metal ions in the coal was low and essentially all the fuel sulphur was emitted from the boiler as sulphur dioxide. The SO_2 emissions amounted to 0.5 kg per GJ input (1.35 lbs per million Btu).

The nitric oxide emissions (548 ppm at 5% oxygen) from the system reflect the fact that the combustion intensity was not high.

The burn-out of the briquettes in the pilot-scale boiler was excellent; it can be anticipated that the thermal penalty due to use of the briquettes in the pulverized form will not amount to more than 1% of the input.

The electrical resistivity of the fly-ash is within the optimum range for good electrostatic precipitator performance and it is unlikely that hot precipitators or fly-ash conditioning will be required during the use of the coal.

The tendency of the coal ash to produce boiler wall slag deposits cannot be disregarded. The ash-fusion and viscosity characteristics suggest that it should be used in a wet-bottom application except in circumstances where it replaces a coal with closely similar properties. Although the coal

ash is lignitic the iron content of the ash is high and may cause problems due to localized reducing conditions.

Both the high and low temperature corrosion potential of the coal are low and both are apparently insensitive to the excess-oxygen level used in combustion.

10. REFERENCES

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2. E. C. Winegartener. "Coal Ash Fouling and Slagging Parameters". Published:American Society Mechanical Engineers 1973.

TABLE 1

Analysis of the Manalta Briquettes

Proximate Analysis			
	Moisture	%	10.8
	Ash	%	16.1
	Volatile Matter	%	38.5
	Fixed Carbon	%	34.6
Ultimate Analysis			
	Carbon	%	51.21
	Hydrogen	%	2.44
	Sulphur	%	0.55
	Nitrogen	%	0.51
	Ash	%	16.13
	Oxygen	%	18.40
	Calorific Value (as received basis)	cal/g	4495
		Btu/lb	8091
Ash Analysis			
	SiO_2	%	37.77
	Al_2O_3	%	12.89
	Fe_2O_3	%	10.19
	TiO_2	%	0.70
	P_2O_5	%	0.40
	CaO	%	15.86
	MgO	%	4.41
	SO_3	%	16.21
	Na_2O	%	0.91
	K_2O	%	0.66

TABLE 2

Volatile Matter Adiabatic Combustion
Temperatures for Selected Canadian Coals

Coal	Moisture Content at Pulverizer	Volatile Matter Adiabatic Combustion Temperature °C
Sundance	16.0	780
Utility Lignite	17.0	660
	0	690
Manalta Briquettes	10.8	1016

TABLE 3

Coal Size Distribution During the Combustion Trials

Screen Size	Combustion Trial		
	1	2	3
> 100 mesh	0.8	0.8	0.7
100 - 140 mesh	8.4	6.9	6.4
140 - 200 mesh	13.3	14.1	11.9
200 - 325 mesh	27.5	22.0	24.1
325 - 400 mesh	4.0	5.5	5.5
< 400 mesh	46.0	50.7	51.4
% Below 200 mesh	77.5	78.2	81.0

TABLE 4

Summary of Combustion Conditions

Test No.	Fuel Firing Rate kg/h	Nominal Excess Oxygen Concentration %	Steaming Rate lb/h kg/h	Flue Gas Composition				
				O_2 %	CO_2 %	CO %	NO ppm	SO_2 ppm
1	76.0 (±2.5)	5	446 (2.5)	4.6 (±0.3)	16.2 (±0.3)	<0.05	548 (±14)	632
2	74.2 (±1.4)	3	445 (±1.4)	2.9 (±0.25)	17.0 (±0.3)	<0.05	435 (±18)	768
3	77.8 (±1.1)	1	464 (±11.6)	1.0 (±0.1)	17.7 (±0.25)	<0.05	421 (±9)	810

TABLE 5

Ash Distribution During the Combustion Trials

		Test No. 1	Test No. 2	Test No. 3
Total Ash Input	Kg	12.25	11.95	12.54
Ash Retained in Boiler	Kg	7.1	7.1	7.4
Electrostatic Precipitator Efficiency	%	86 - 87	90 - 92	

TABLE 6

Analysis of Furnace Deposits: Combustion Test No. 1

Test Conditions: Fuel Rate 76 kg/h
Excess Oxygen 4.6%

Ash Component	Furnace Bottom Deposit	Furnace Wall Deposit	Transition Piece Deposit	Superheater Deposit	Air Heater Deposit
Ash Component					
1 SiO_2 %	49.00	46.32	44.89	41.10	46.98
2 Al_2O_3 %	13.18	13.01	13.67	14.34	13.53
3 Fe_2O_3 %	10.57	10.83	10.92	12.16	10.92
4 TiO_2 %	0.75	0.75	0.80	0.85	0.79
5 P_2O_5 %	0.52	0.47	0.48	0.51	0.50
6 CaO %	16.62	15.86	17.42	18.48	17.10
7 MgO %	3.81	3.05	3.18	4.97	4.49
8 SO_3 %	3.74	9.66	7.56	6.62	7.25
9 Na_2O %	0.89	0.85	0.73	0.79	0.76
10 K_2O %	0.71	0.71	0.62	0.65	0.64
Ash Fusion Temperatures °C					
Oxidizing Atmosphere					
Initial Deformation	1190	1199			
Spherical Deformation	1220	1220			
Hemispherical Deformation	1250	1240			
Fluid Temperature	1360	1360			
Reduc Atmpsohere					
Initial Deformation	1160	1171			
Spherical Deformation	1188	1204			
Hemispherical Deformation	1210	1206			
Fluid Temperature	1293	1288			

TABLE 7

Analysis of Furnace Deposits: Combustion Test No. 2

Test Conditions: Fuel Rate 74.2 kg/h
Excess Oxygen 2.9%

Ash Component	Furnace Bottom Deposit	Furnace Wall Deposit	Transition Piece Deposit	Superheater Deposit	Air Heater Deposit
Ash Component					
SiO_2	47.50	45.24	43.50	42.00	43.69
Al_2O_3	14.23	12.83	12.80	13.91	12.81
Fe_2O_3	11.45	11.14	10.84	11.50	10.73
TiO_2	0.78	0.74	0.73	0.81	0.72
P_2O_5	0.48	0.44	0.47	0.56	0.46
CaO	16.41	15.95	17.02	17.47	16.99
MgO	4.35	3.37	3.47	5.01	4.18
SO_3	2.46	9.88	8.08	7.08	7.37
Na_2O	0.95	0.88	0.76	0.76	0.77
K_2O	0.72	0.71	0.65	0.63	0.65
Ash Fusion Temperature °C					
Oxidizing Atmosphere					
Initial Deformation	1220	1200			
Spherical Deformation	1230	1230			
Hemispherical Deformation	1240	1250			
Fluid Temperature	1380	1340			
Reducing Atmosphere					
Initial Deformation	1180	1180			
Spherical Deformation	1200	1216			
Hemispherical Deformation	1210	1220			
Fluid Temperature	1350	1290			

TABLE 8

Analysis of the Water Soluble Material in the Low Temperature Deposits

Test No.	Water Soluble Components		Corrosion Probe Temperatue		
			104°C	120°C	138°C
1	SO4	mg	7.2	2.6	2.0
	Fe	mg	0.1	0.2	0.2
	Mg	mg	0.3	0.1	0.1
	Ca	mg	0.6	1.6	0.8
	Na	mg	1.5	0.2	0.1
	Free H_2SO_4		0.7	Trace	Trace
	Free H_2SO_4	$mg/cm^2/h$	1.3	-	-
2	SO4		3.4	3.0	2.5
	Fe		0.2	0.6	0.6
	Mg		0.3	0.1	0.1
	Ca		1.0	1.5	0.9
	Na		0.5	0.1	0.1
	Free H_2SO_4		1.1	Trace	Trace
	Free H_2SO_4	$mg/cm^2/h$	2.0	-	-

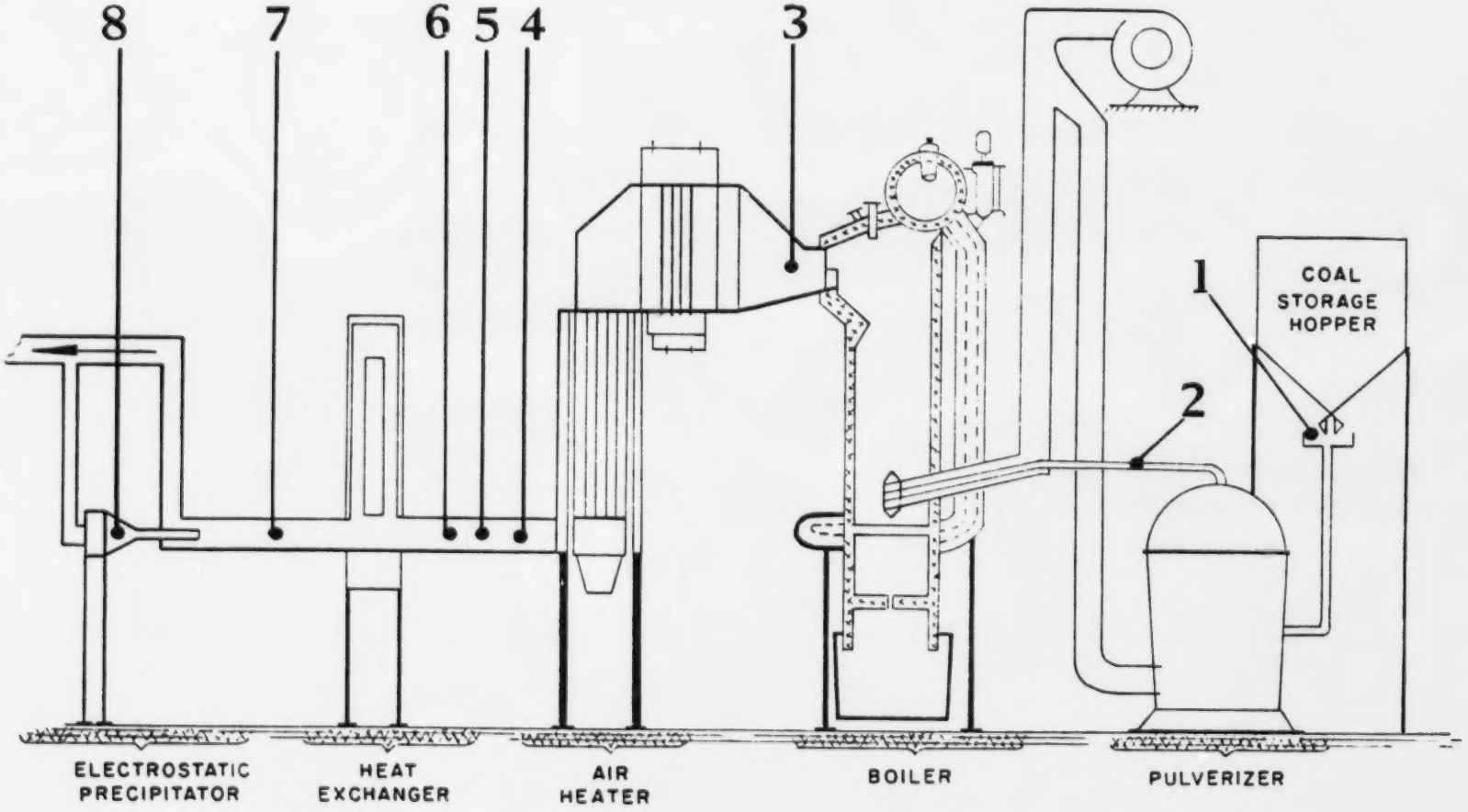

FIGURE 1. Schematic Illustration of the Pilot-scale Boiler Showing the Sampling Stations

FIGURE 2. The Effect of Excess Oxygen Level on the Unburnt Carbon Content of the Fly Ash.

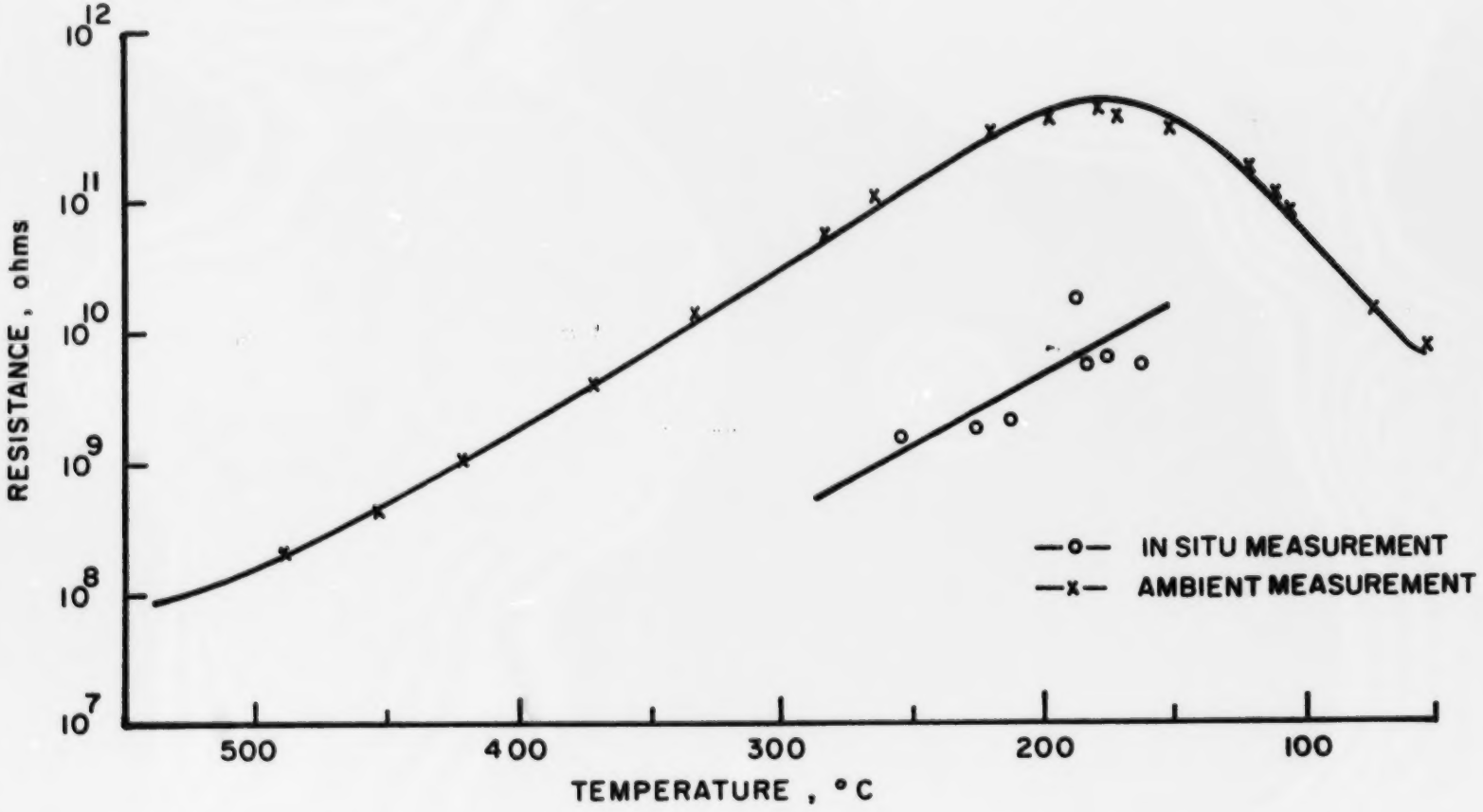

FIGURE 3. The Effect of Temperature on Fly Ash Resistivity; Ambient Atmosphere and "In Situ" Measurements

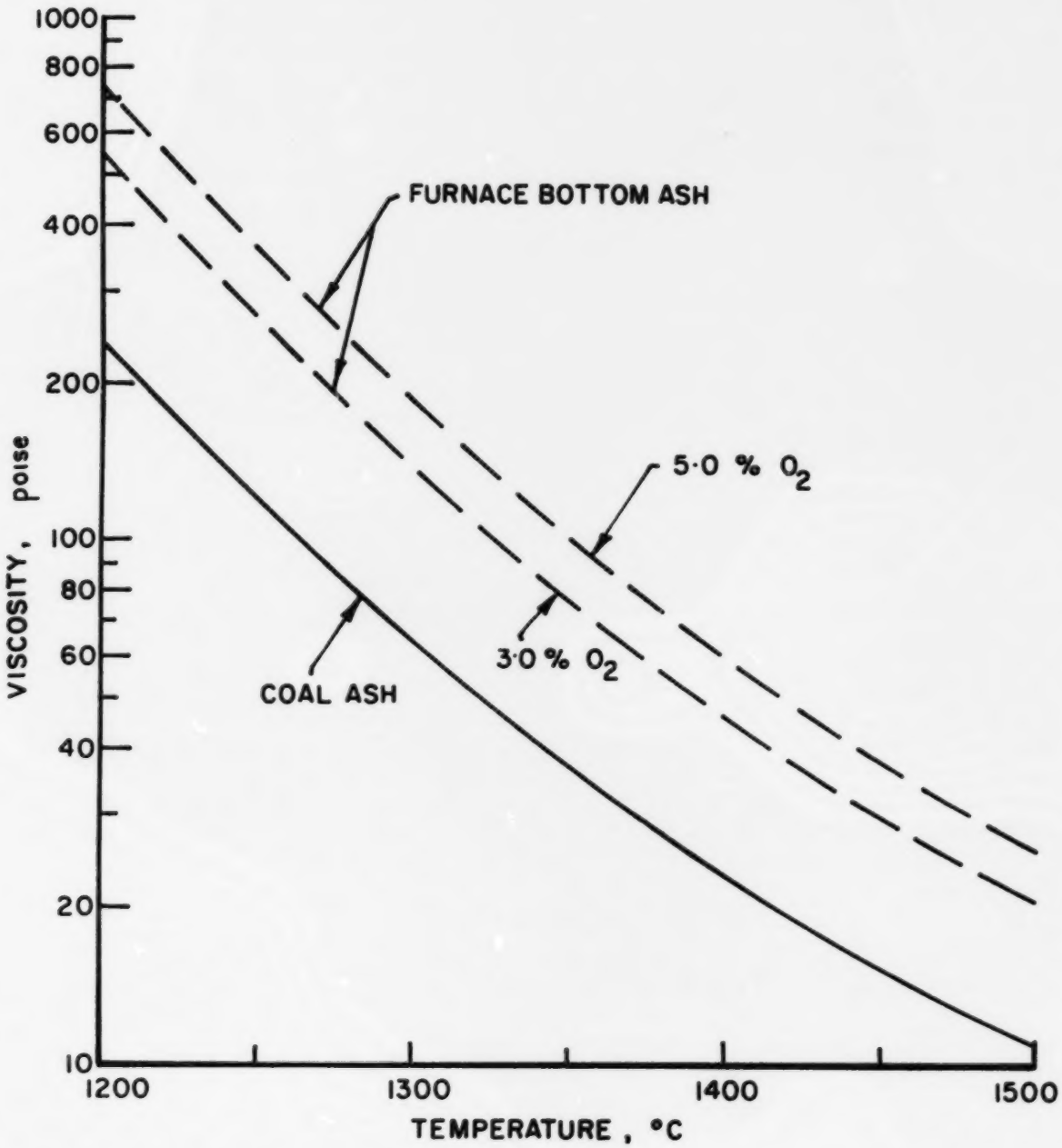

FIGURE 4. The Relationship Between Slag Viscosity and Temperature: Calculated From Ash Analysis